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TITLE

CAD/CAM IN THE PLASTICS INDUSTRY STATE OF THE ART TECHNOLOGY

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RÉSUMÉ

Dans la plupart des pays industrialisés, la CAO/FAO est de plus en plus utilisée, particulièrement dans l'industrie des plastiques. Cet article dresse d'abord un tableau sommaire des perspectives générales que présente cette technologie, et discute brièvement les répercussions socio-économiques de son implantation. On y discute également du potentiel d'applications dans l'industrie des plastiques et plus spécifiquement dans l'industrie canadienne. Par la suite, plusieurs exemples des travaux de recherches et de développement faits à l'étranger sont rapportés. Finalement, un plan d'action dans ce domaine est proposé pour l'Institut de génie des matériaux. Enfin une bibliographie assez importante de 38 articles vient compléter cette étude.

ABSTRACT

In all major industrial countries, there is a growth in the use of CAD/CAM technology, particularly in the plastics industry. This article presents a summary of the general perspectives offered by this technology, and discusses briefly the socio-economic implications due to its implementation. We also discuss the potential applications in the plastic industry specifically in Canada. Afterwards, many examples of foreign research and development projects are reported. Finally, a plan of action in this field is proposed for the Industrial Materials Research Institute. A bibliography of 38 articles is included.

INTRODUCTION

CAD/CAM technology (Computer-Aided Design and Computer-Aided Manufacturing) has become an essential element in all stages of the production process. This process is based principally on human resources and the tools that can be made available for them. In this context, CAD/CAM is mainly concerned with combining human technical expertise with the power that can be provided by computer technology.

The main purpose of this paper is to review some of the potential uses of CAD/CAM, particularly in the plastics industry sector. After a careful review of developments in the area, we will try to explain some of the multiple facets of this technology. Later, we will examine CAD/CAM applications in the plastics industry, and the latest research and development efforts in this area.

1. CAD/CAM - SYMBOL OF MULTIDISCIPLINARY EFFORT AND PRODUCTIVITY

CAD/CAM technology has become the most radical element in the development of manufacturing industries in this decade. This technology already pervades the entire development cycle of a product, from the moment of its original conception to the time it is actually manufactured. However, it is almost impossible to give a precise definition of CAD/CAM, not only because it is at the very forefront of knowledge, but because the area is constantly evolving. Nevertheless, we may find it convenient to say that a person uses CAD/CAM whenever he interacts with a computerized system, for the purpose of designing or manufacturing a given object.

In its principal role, which is to provide a link between the design and manufacturing stages, CAD/CAM offers the user the advantages of a unique method. This concept is illustrated in Figure 1, which shows that the interaction between the designer and the graphic screen presents certain similarities with the natural dialogue that exists between an operator and his machine. Figure 2 shows the main elements of an interactive work station [1], which can be used to define and evaluate an object's performance; to manipulate graphic and alphanumeric data or even to communicate with a numerically controlled machine tool. This type of rapid communication is always the most important factor in determining the productivity of any business. CAD/CAM, whose main role is to act as a catalyst among the various engineering functions, has been especially geared to the needs of the following groups:

- designers and engineers in research departments;
- analysts involved in the problems of manufacturing methods;
- process engineers and plant technicians:
- NC machine tool programmers;
- industrial designers, etc.

Through the use of a common language, which can be adapted to the needs of each particular industry, CAD/CAM technology is

capable of providing a wide variety of services, for example:

a) Assisting in the process of designing and developing a new system, model, or product.
b) Providing qualitative and quantitative data which can be used in making design and evaluation decisions affecting the system.
c) Maintaining files on parts records and numerical data relative to the properties of the marerials used.
d) Designing equipment and tools required for the production process.
e) Evaluating the performance of a model by simulating loading conditions.
f) Exploring certain geometric modifications or new operational requirements, by making direct interventions on the model itself.
g) Generating instructions for numerically controlled machining procedures used in the manufacturing process.
h) Planning the manufacturing procedures by defining the nature and sequence of operations.
i) Inventory control and production schedules.
j) Developing a quality control system through a computerized inspection and evaluation program.
k) Integration of all industrial functions within a flexible production system.

Thus, CAD/CAM can be used to develop a product with a considerable economy of time. It makes it possible to study an object thoroughly without having to produce a prototype. The use of this technology can considerably improve productivity, develop a better awareness of the organization of the system and expand human creative capacity [2, 3].

2. EVOLUTION AND GENERAL PERSPECTIVE OF CAD/CAM TECHNOLOGY

Figure 3 shows the progression and historical development of the CAD/CAM concept, which has now reached an era of exponential growth [4]. The evolution of this technology depends on two important factors: equipment performance and benefits to the user. CAD/CAM technology is not unique in the sence that it can be adapted to the particular industry where it has been implemented. Thus, the expansion of this technology will depend on the development of new application modules dealing with different industrial sectors. Figure 4 shows expected growth figures for the world markets, according to the type of application [5].

Figure 4 shows that for the period 1980-1986, the number of graphic work stations used throughout the world will go from 17,000 to 100,000. In this same period, sales figures will go from 900 million to 5.8 billion dollars per year. Table 1 shows the evolution of the United States market for several industrial sectors [6]. At present, the most difficult stage in CAD/CAM implementation is the complete integration of all industrial functions, that is, the integration of the design, manufacturing, planning and control stages. This type of integration will be achieved through the implementation of a modular structure composed of many sub-groups which, when taken together, will form a flexible production system (see Figure 5).

Within this type of organization, the information gathered at the design stage will be made available to engineers working in the manufacturing process and vice versa. It is in this interlocking of design principles and manufacturing requirements, that the realization of this concept will be most efficient. The role of group technology will become more and more necessary for the consolidation and standardization of data. This will considerably reduce the time and cost involved in distributing and sharing data among all the different functions of the industry.

3. SOCIO-ECONOMIC IMPACT OF CAD/CAM TECHNOLOGY

At present, the adaptation of this technology to the industrial sector requires a reorganization of the plant's operational procedures. This has led to certain problems in the distribution of responsabilities and personnel allocation, which have to be resolved. There will also be certain changes involving production methods which will affect individual discipline. It is important to remember that the use of CAD/CAM technology involves a concrete representation of technical knowledge in a form that can be clearly and easily grasped. Through this visual language, the expression of a concept acquires a great persuasive and convincing force.

There are many who believe that the adoption of CAD/CAM tehcnology will cause unemployment. It is important to find a way to define how this technology may tranform and create employment. It is necessary to point out that the inability to use these techniques may cause even more dramatic job losses. CAD/CAM can generate large numbers of new jobs because large numbers of specialists are necessary to develop and use it [7].

CAD/CAM technology must be seen as a complement to and not as a substitute for intellectual power. This should serve as the basis to construct a new industrial framework and as the inspiration for all development projects. Once an industrial plant has decided to acquire CAD/CAM technology, it is important to involve a significant number of employees in the project, so that they can have the opportunity to put their experience to good use. In this way, it will be possible to develop an awareness of productivity requirements, and a dedication to cooperative work, which will ensure the success of the venture [8].

Obviously, the size of the business is an important factor, especially at the level of financial resources. Nevertheless, very positive effects have been registered in small and medium-sized industries. CAD/CAM can

be considered not only as a production tool, but also as a development factor [9]. Finally, data collection should be regulated with a certain measure of prudence, in order to avoid overloading the individual's capacity to deal with it. Thus, one of the concerns would involve a certain amount of discrimination in using the data, so that simplified models can be used as the basis for analysis, synthesis and interpretation [10].

4. HIGHLIGHTS IN THE USE OF CAD/CAM TECHNOLOGY IN THE PLASTICS INDUSTRY

Even though CAD/CAM technology was initially developed in the space industries, it no longer belongs in the realm of science fiction as far as the plastics industry is concerned. CAD/CAM technology has been progressively used in this industry since the beginning of the 70's especially for mould machining. It was only towards the end of 1978 that the technology was adapted to the design of parts, tools and equipment. An increasing demand for better quality products and the pressures put on manufacturers to shorten their production time, have forced the industry to accept CAD/CAM developments. At present, progress is being made in areas such as the standardization of methods, the preparation of drawings and the automatic control of machinery. Thus, processors and mouldmakers have been able to improve the tools used and the conditions under which the moulding process takes place. The following is a list of some fo the potential applications of CAD/CAM technology in the plastics industry:

a) The selection of materials according to application requirements.
b) The construction of tools on the basis of standardized components.
c) The production and rapid revision of blueprints.
d) The analysis of production cycles and evaluation of product costs.
e) The optimization of moulding conditions; cycle time, pressure and temperature.
f) The best possible product design through a better balance of flow rates and pressures.
g) The determination of temperature profiles and cooling time.
h) The analysis of stresses and strains during the process of designing products, mould parts or machines.
i) The use of robots for insert loading, transfer between stations, plating, heat treatments and the application of adhesives, lubricants, etc.

j) Parison programming in the blow moulding process.

k) Tne manufacturing of patterns and electrodes for Electro-Discharge machining with a self-correction for mould shrinkage.

l) Checking the path of the cutting tool for the machining of complex cavities.

m) The machining of symmetrical elements, male and female pieces with the same program and mirror image technique.

Some companies say that they have made substantial savings by using this technology. The following are two examples: General Electric says that they have been able to save 100 million dollars a year, by the use of better mould designs [11]. In the same way, Firestone Tire and Rubber has been able to cut the time necessary to develop a tire mould from 21 to 2.5 days. This company says that they have used some 400 sub-routines for the total analysis and design of a new mould [12]. These examples show the extent to which CAD/CAM technology can be a significant asset to the industry.

The introduction of CAD/CAM technology in the plastics industry can also represent an efficient educational tool that can offer a solution to the constant shortage of qualified personnel. It can also help the industry to improve its productivity by:

- introducing high quality products;
- cutting delivery times;
- decreasing the cost of production;
- standardizing working methods.

5. CAD/CAM AND THE CANADIAN PLASTICS INDUSTRY

There is no doubt that CAD/CAM technology has a place in the Canadian plastics industry. The use of computerized systems dates from 1975, when mini-computers and microprocessors were introduced [13]. However, the application of this technology is often limited to the control of production and manufacturing processes. Mini-computers are used to control production schedules and for preparing statistics about the rejection rate and calculating yield and material consumption. They are also used to control the finances of the enterprise and to estimate costs. Microprocessors in particular are used for automatic control and regulation. In this way, operational conditions are checked and adjusted during the moulding process or during the machining of the mould itself. Today, of about 250 mould-makers, 30% already own equipment for numerically controlled machining and their number continues to increase. In Canada, these installations increased by 31% in 1981, over the number existing in 1980 [14].

Several technical colleges such as Mohawk, Seneca, Durham and George Brown, in Ontario, have recently installed CAD/CAM systems for training qualified technicians for the plastics industry. A survey conducted by tne Canadian Manufacturers' Association and the Department of Industry and Commerce reveals that there is a growing interest in CAD/CAM among respondents [15].

Also, other important projects are being carried out by the Department of Mechanical Engineering of the University of British Columbia in Vancouver and by the Canadian Institute of Metalworking in Hamilton. These efforts are mainly oriented to complex surface modeling and to mould machining on numerically controlled machine-tools.

Nevertheless, few Canadian companies use CAD/CAM technology for the entire product development cycle, including design, analysis and

manufacturing. With the exception for some large captive companies that already have this type of facilities, the number of CAD/CAM installations in small companies is much more modest. Even now, many moulds used in Canadian industries are developed, analyzed and manufactured in the United States, Japan or Europe. A good number of the moulds made in the United States are installed in American processing companies and only the finished products are exported to Canada, where thet are assembled. Here is one example of a draining away of tasks that are linked to the natural development cycle of CAD/CAM technology in Canadian industry. Few Canadian processors use robots in their moulding operations. In this respect, we are far below the world average, where the plastics industry, with 13% of industrial robotics installations [16, 17], ranks second only to the automobile industry.

In this context, it is necessary to look into the trade balance deficit in the plastics sector. This deficit represents about 1.25 billion dollars, of which 65% is due to imports of finished products and equipment [18]. In 1981, the Canadian plastics industry was the third largest employer in the manufacturing sector, with 60,000 direct jobs and a domestic market of $5.6 billion. In the same year, export figures reached 420 million dollars for finished products and 105 million for moulds. We have estimated that the annual market for moulds in Canada is about 5,000 moulds, with a total average value of 250 million dollars [19]. Nevertheless, in a total of 2,000 industries, including processors, mouldmakers and manufacturers of raw materials, only 250 had 100 employees or more.

Despite the existence of some encouraging signs, we lag behind other industrialized nations as far as the installation of CAD/CAM facilities are concerned. Soon, the market will no longer be able to tolerate this situation.

6. GENERAL REVIEW OF RESEARCH AND DEVELOPMENT EFFORTS IN OTHER COUNTRIES

The growing demand for high quality products and the effects of inflation have contributed to an increased awareness of the importance of CAD/CAM research and development programs. The MOLD FLOW system is one of the first results of a scientific research program that looked into the flow process in injection moulds. This system was developed in Australia between 1975 and 1978 by a group of researchers headed by Colin Austin. At present, the system is marketed by General Electric through its MARK III computerized network [20]. This program was based on two basic principles: the balanced of flow rates and a constant pressure gradient. The system makes possible not only a simulation of the process of filling the mould, but also offers the following possibilities:

a) dimensioning the feeding system;
b) determination of optimal moulding conditions;
c) an analysis of the effects of the material shearing rates;
d) the best possible product design by introducing changes in shape, thickness or raw materials.

In 1979, when the MOLD FLOW process was introduced in the market, 2,000 moulds were analyzed with this system: 60% in the United States, 30% in Japan and 10% in Europe. It is important to point out that there are 5,000 American companies that specialize in the production of moulds. In Europe, GE maintains technical assistance centres that serve many cities such as Evry in France, Russelsheim in Germany, Milan in Italy, Amsterdam in Holland and Warrington in England. Following is a list of some of the larger companies that have experimented with the MOLD FLOW system [21]:

- IN THE RAW MATERIALS SECTOR:
  General Electric, Mitsubishi Chemicals, Montedison, Snia Viscosa.

- HOUSEHOLD ELECTRIC APPLIANCES:
  General Electric, Hitachi, Matsushita, Sony, Toshiba

- AUTOMOBILE SECTOR:
  General Motors, Toyota, Mazda, Mitsubishi Motors

- ELECTRONICS SECTOR:
  Minolta, Kodak, Olivetti, Ticino, ITT, Canon

Very recently, research carried out by Application Engineering Corp. has led to the marketing of another system called MOLD COOL, which is used for the thermal analysis of moulds. This system is available in some 600 cities throughout the world through the information services of General Electric (GEISCO) [22, 23]. The program MOLD COOL, which was developed initially for the study of injection moulds, was later adapted to thermosetting, blow moulding and thermoforming processes. It makes it possible to simulate heat transfer in the mould during the transition period and design the cooling system by taking into account the following factors:

a) the calculation of the amount of heat and of pressure losses in the cooling circuit;
b) the optimization of the moulding cycle and operational requirements (flow rate, pressure, temperature).

In the United States, General Electric has adopted CAD/CAM to increase productivity of the injection moulding process [24]. It is important to point out that GE has 1,000 presses in operation and processes some 130 million pounds of plastic per year. At the same time General Motors has implemented one of the most advanced programs for generating mirror images and solid models [25]. General Motors manufacturers more than 1,000 moulds and processes about 600 million pounds of plastic per year.

In the manufacturing sector, the work carried out by National Computer System in Minneapolis has made possible the introduction of three new programs: COMPUGRAPHICS, COMPUSCANNER and

COMPUMILL. These programs are used for obtaining a numerical definition of the pieces, for measuring 3D prototypes and for machining the moulds [26]. Another significant research program has been carried out at Cornell University in New York State. This program analyzes not only the flow and cooling systems, but it also makes possible the dimensioning and selection of mould components [27]. It is also used for generating tapes used for numerically controlled machining. This research is sponsored by the National Science Foundation and an industrial consortium including companies such as GM, GE and others.

In the United Kingdom, among the many projects carried out by the CAD/CAM centre in Cambridge, we could single out the POLYSURF and DUCT programs, which are used for machining moulds and dies. The cutting path tools used for machining complex surfaces can be generated with the help of these programs and verified on a graphic screen [28]. Other research centres such as production engineering centres in Glasgow, Salford and Birmingham, have also made significant contributions to the advancement of CAD/CAM technology in the plastics industry. Other important research projects are also being carried out by the Department of Mechanical Engineering of Imperial College in London, and by the Polymer Department of the University of Manchester [29, 30].

In the Federal republic of Germany, several CAD/CAM research and development programs have been running at the Plastics Processing Institute (IKV) in Aachen and the German Plastics Institute (DKI) in Darmstadt, since 1975. The results of some of these studies have been reported by the Rubber and Plastics Research Association (RAPRA) and the Verlag Dusseldorf Institute (VDI). The CADIM (Computer Aided Design for Injection Molds) program has been used to develop several decision trees that can be used for selecting mould types and calculating the optimal number of cavities. Other programs have also been developed for the analysis of stresses and strains in the mould components, for the analysis of flow and for the choice of materials [31, 32, 33].

In France, an increase in the use of computers in plastics manufacturing processes has led to the implementation of several CAD/CAM research programs. These projects have been generally concerned with tool design and the optimization of automatic process control. Studies carried out by the Centre for Technical Research in the Mechanical Industries (CETIM) have made significant contributions to the development of CAD/CAM technology. Of special importance have been the studies done in Nantes on the design of tools used in the plastics and rubber industries. Design methodology and calculation, charts and scale diagrams have also introduced [33, 34]. Similar work is being done at the National Plastics School in Yonnax; and at the Materials Processing Centre and the Centre for the Study of Plastics in Paris [36].

In Japan, CAD/CAM technology was introduced into the plastics industry in 1978, with the development of the CAD/CAM (Computer Aided Design, Drawing and Manufacturing for Dies and Molds) system construction, was developed by Matsushita Electric Industrial Co. It has three main objectives:

1. the optimization of complex die and mould design for the electronics industry;
2. the automatization and standardization of tool drawing procedures;
3. helping mould makers with numerically controlled machining procedures.

Other computer aided mould design research projects have been undertaken by such companies as Toshiba Machine, Fujitsu Kasei and Sekisui Machinery [38].

7. A PROPOSED PLAN OF ACTION FOR THE INDUSTRIAL MATERIALS RESEARCH INSTITUTE IN THIS FIELD

The Industrial Materials Research Institute has to establish a CAD/CAM research and development program geared to the needs of the Canadian plastics industry. The objective of this program is to provide the technical support necessary for the implementation of CAD/CAM technology in this sector. The first phase of this program will consist of developing a data base to help with tool and product design. The data base will gather information about the physical properties of materials, fabrication characteristics and standardized geometrical elements. Later, we should focus on the area of software, and will develop tools for the study of flow and heat transfer; and for the analysis of mould stresses and strains.

At the beginning, the work will be concerned mainly with the injection moulding process. Then, the IMRI will extend its activities to include other plastic manufacturing processes, such as extrusion, blow and compression moulding. This program will be of interest mainly to mouldmakers and processors; but it may later be expanded to include projects of interest to equipment manufacturers. Over the long term, we expect to extend our work to pressure casting process used with metals, and to establish a close link with other activities of tne Institute such as projects involving the application of robotics to automatic welding.

CONCLUSION

CAD/CAM technology has made significant advances in the international sphere and Canadian industry must adopt it if it wants to remain competitive. Nevertheless, the success of CAD/CAM programs is largely dependent upon the capacities and motivation of the personnel involved. We must admit that there is a natural resistance to change and a tendency to want to keep doing things in the traditional ways. For small companies, the acceptance of this new technology represents both a challenge and a development tool. In these small companies, CAD/CAM can help solve problems faster ans ensure the greater versatility that gives them their main advantage. CAD/CAM applications will continue to expand. However, they will always be conditioned by the nature and diversity of the industry.

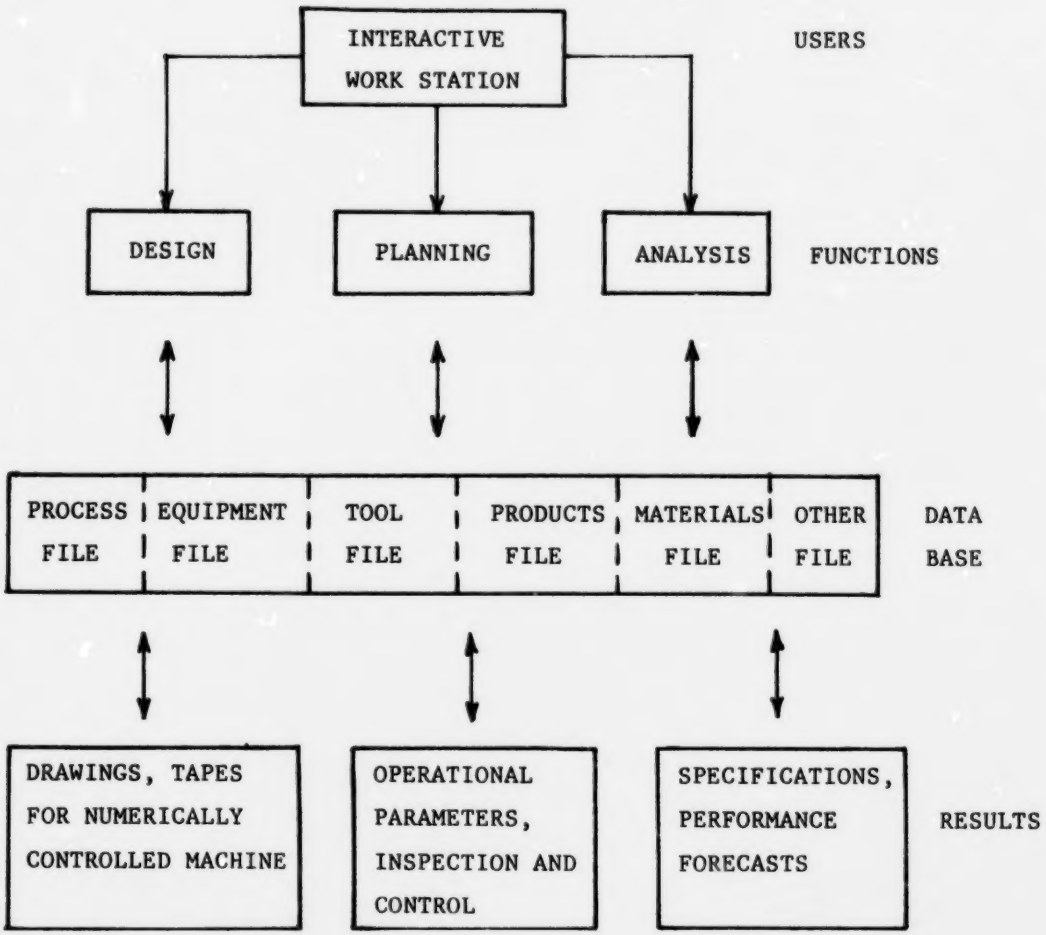


FIG. 1 THE CAD/CAM CONCEPT

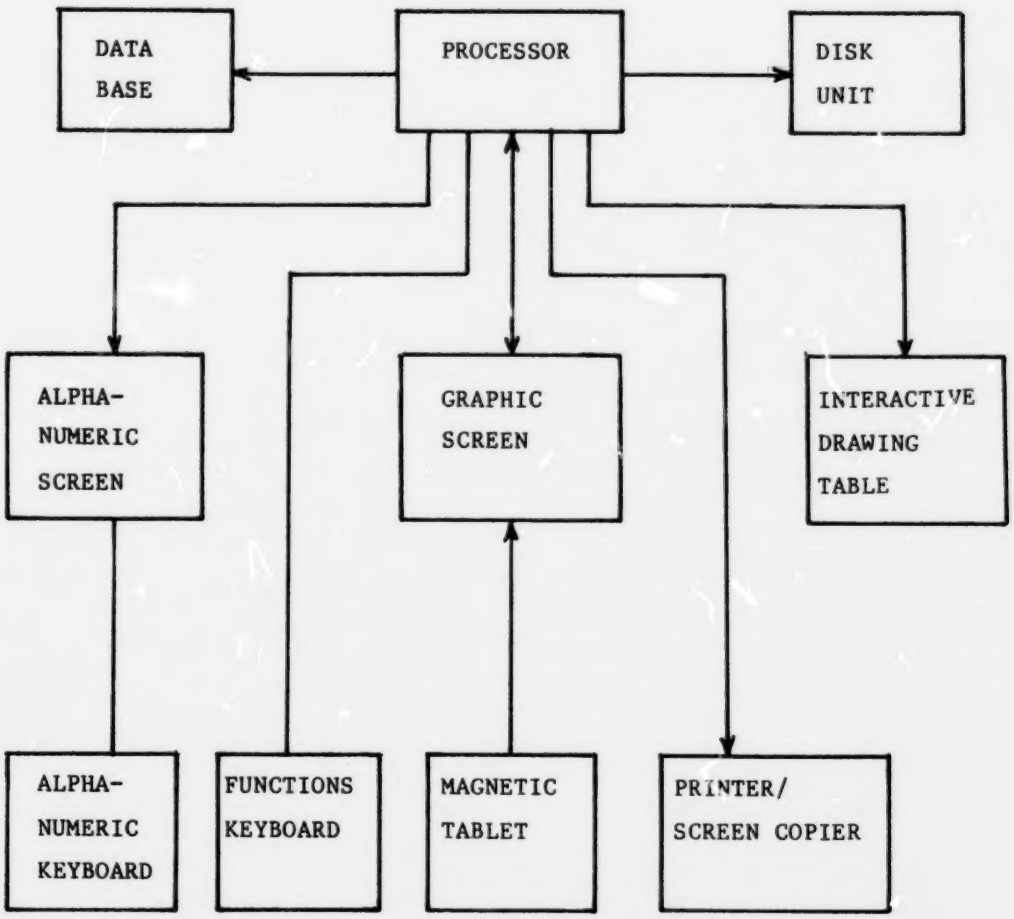
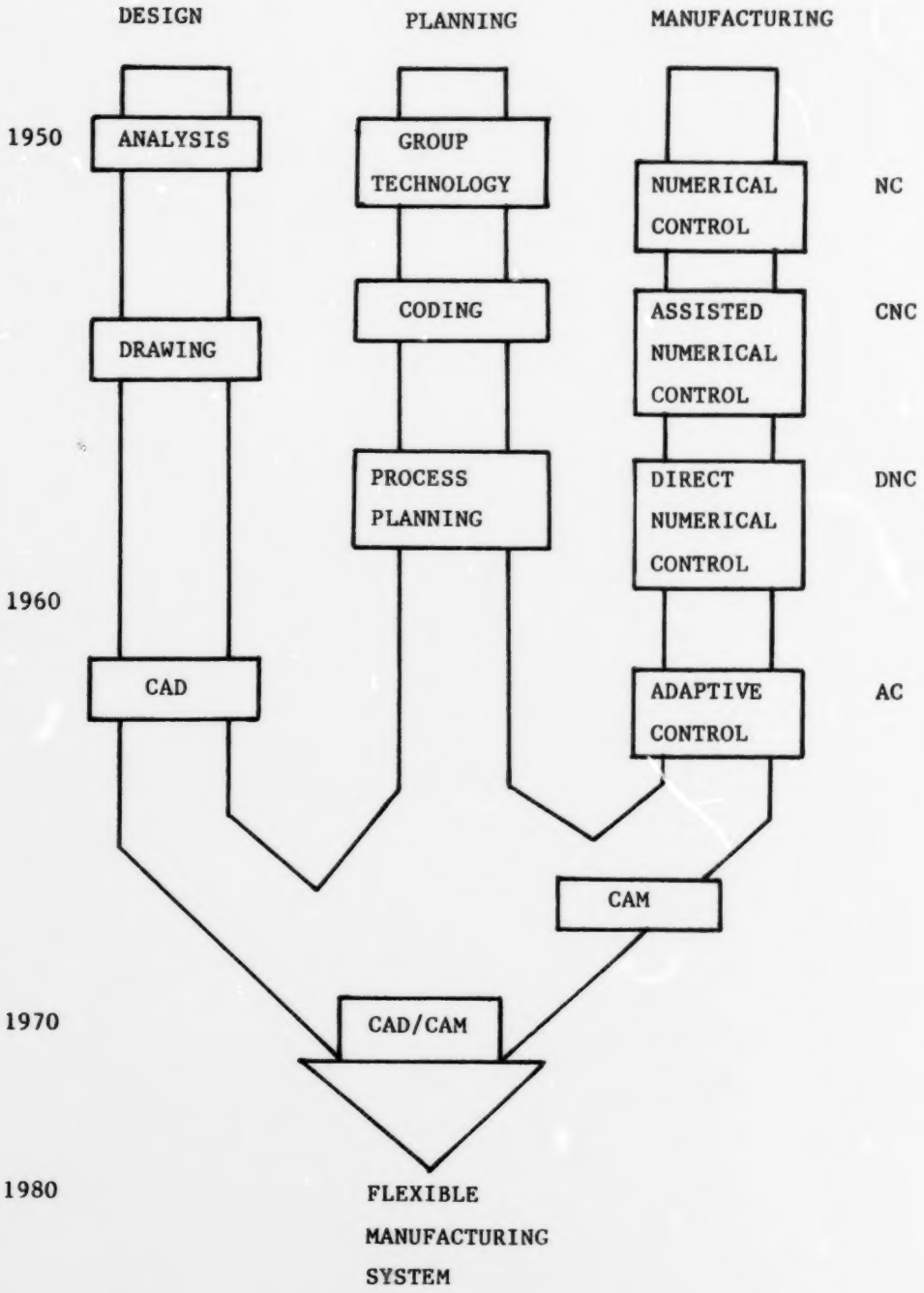


FIG. 2 INTERACTIVE WORK STATION

FIG. 3 HISTORIC EVOLUTION OF CAD/CAM



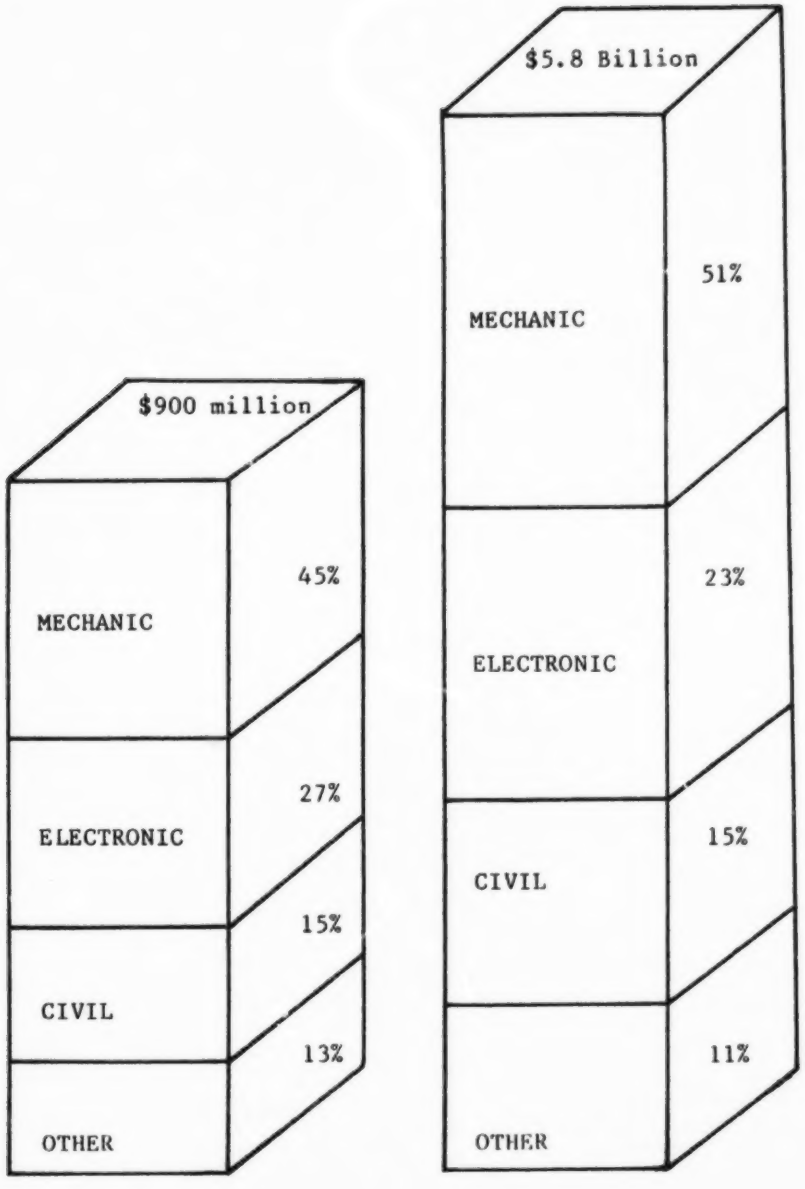


FIG. 4 FORECASTS OF CAD/CAM GROWTH IN VARIOUS WORLD INDUSTRIAL SECTORS

	1978	%	1979	%	1980	%	1981	%	1984	%
Mechanic	$65	+60%	$120	+85%	$199	+66%	$310	+56%	$1,100	53%
Electronics	49	+36%	90	+84%	149	+66%	215	+45%	396	28%
Civil Engineering	25	+50%	50	+100%	75	+50%	108	+45%	308	42%
Cartography	15	+70%	30	+100%	70	+133%	105	+45%	242	37%
Other	11	+60%	20	+82%	17	-15%	27	59%	154	73%
TOTAL	$165	+60%	$310	+88%	$510	+65%	$765	+50%	$2,200	44%

TABLE 1. ESTIMATED ANNUAL GROWTH OF CAD/CAM MARKET IN THE UNITED STATES BY APPLICATION ($ MILLIONS)

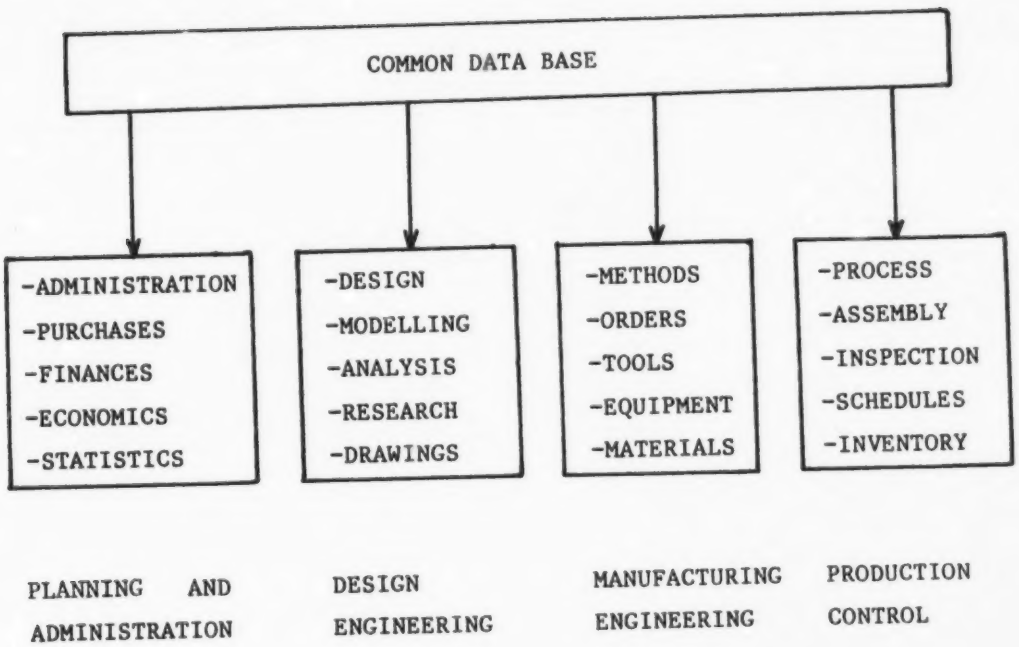


FIG. 5 CAD/CAM FLEXIBLE MANUFACTURING SYSTEM CONCEPT

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